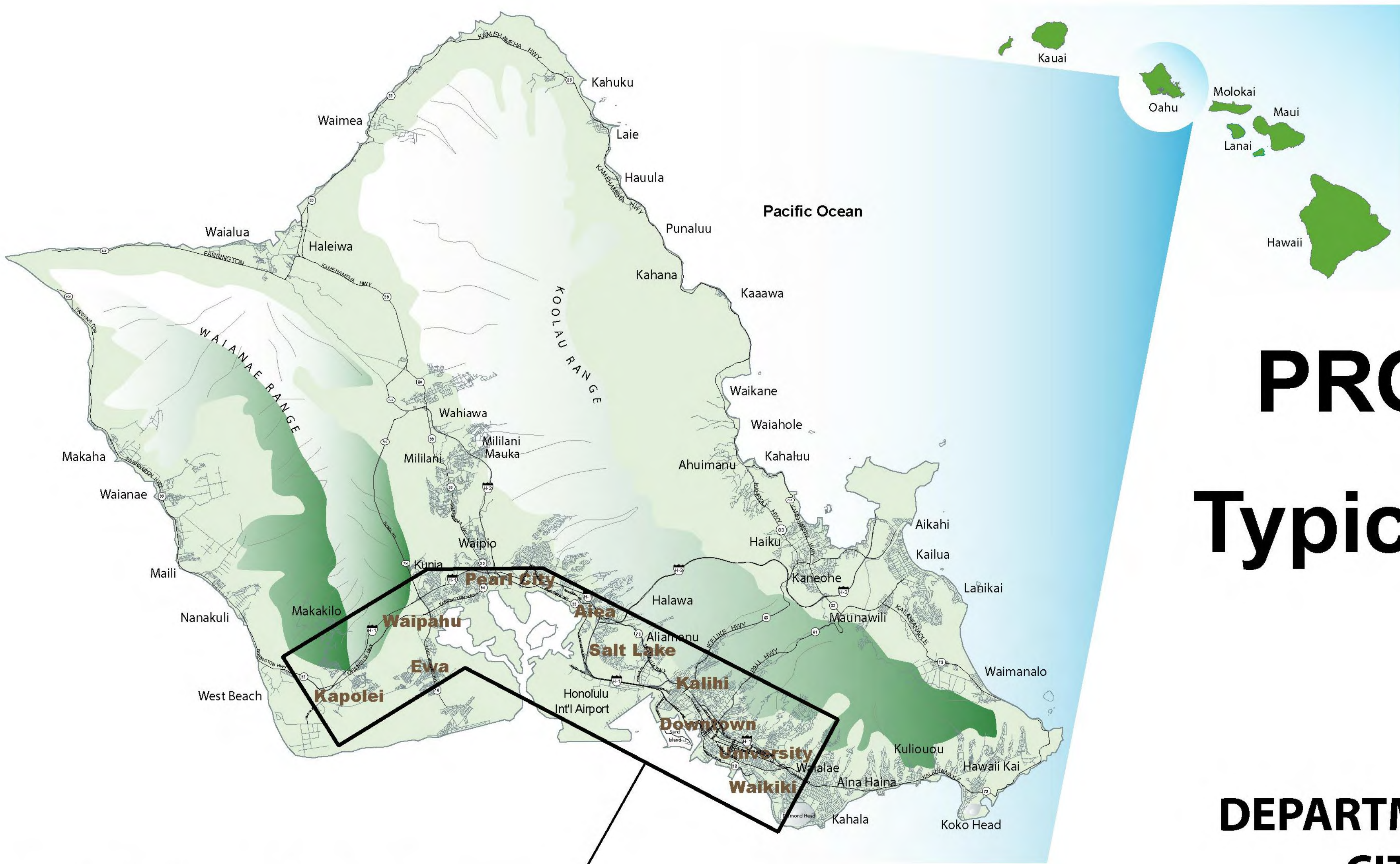
HONOLULU HIGH-CAPACITY TRANSIT CORRIDOR PROJECT

ALTERNATIVES ANALYSIS



PROJECT LOCATION

PRODUCT 9.4 FINAL

Typical Structural Details

DEPARTMENT OF TRANSPORTATION SERVICES
CITY AND COUNTY OF HONOLULU

NOVEMBER 2006

AR00067186

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Scope of Conceptual Structure Design

This conceptual design investigation addresses the most viable structural solutions and details for use in transit corridors assuming design-build project delivery. It addresses high occupancy vehicle (HOV) managed lane solutions for two and three lane systems, and applicable options for fixed guideways including rail, maglev, and monorail.

Managed Lane Alternatives (High Occupancy Vehicle (HOV) Lanes)

AASHTO designed bridges for rubber tired vehicles normally require less design load capacity per square foot than guideways supporting rail transit. This varies with length of span and the number of rubber tired lanes that will fit within the width of any bridge. Such determination can therefore not be made arbitrarily, and only the difference in girder configurations for HOV versus rail are demonstrated. Three solutions are investigated for HOV facilities, each requiring a different width of structure as follows:

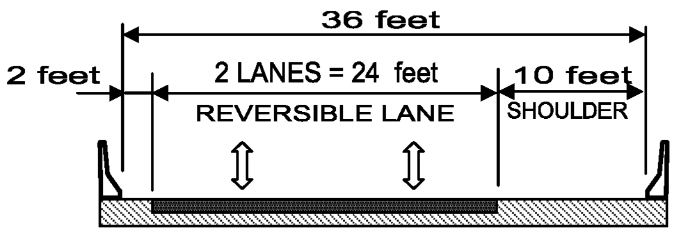

Figure 1-1. Two Lanes Reversible

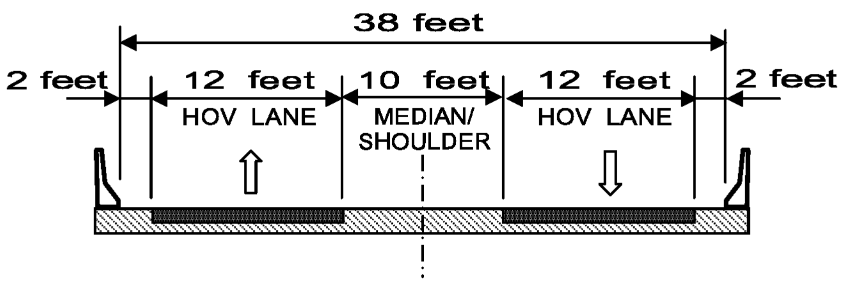

Figure 1-2. Two Lanes- One Each Direction

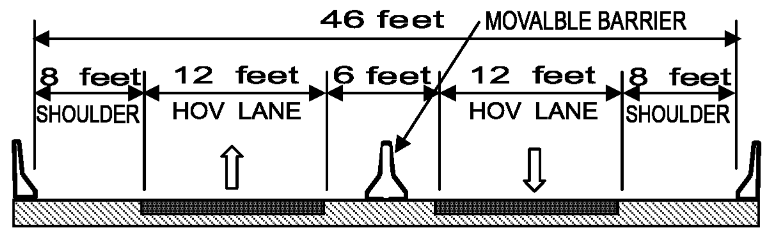

Figure 1-3. Three Lanes with Reversible Median

Fixed Guideways

Fixed guideway requirements are influenced by their need to accommodate aerial, subway, and at-grade along the same corridor. Some at-grade solutions require dedicated right-of-way because the power source cannot be shared with pedestrians and rubber tired vehicles. This report concentrates on the requirements only for aerial guideways.

The only fixed guideway transit systems being considered here are presently in use in the world as a cost effective, reliable, and environmentally sound transit option for urban mass transportation. Transit vehicles are to be accessible to passengers using a high platform rather than from the street level. These include:

- Light Rail Vehicles employing overhead contact system (OCS) lines, or 3^{RD} Rail. It is technically feasible to have retractable 3^{RD} Rail shoes;
- Vehicles employing magnetic levitation technology;
- Wide body rubber tired monorail vehicle.

It is not the purpose of this report to investigate each in depth, but some of the characteristics affecting the structure are as follows:

Light Rail Vehicles

Light rail is the most common solution to meeting every urban operational, performance, and reliability requirements. Shared at-grade use with other vehicles at street level requires overhead catenary wires, and these then also become a visual aspect of the aerial guideways. Combined 3^{RD} Rail with retractable shoes avoids the need for OCS poles on aerial guideways and allows vehicles to also use OCS for at-grade operations. There are several light rail vehicle manufacturers and therefore, there is cost competitiveness. The maximum grade guaranteed by manufacturers is usually 6 percent.

Magnetic Levitation Vehicles

Most maglev technology is aimed at high-speed. The only medium speed transport system known to be under construction for urban use is the Japanese Chubu CHSST. Extensive research has been bone by the US Federal Transit Administration’s Office of Research, Demonstration, and Innovation. The conclusion is that such a system is a reliable option. Its main advantages are that it is able to traverse grades significantly greater than 6 percent, and is noise and vibration free. Its use at-grade requires investigation, but its ability to accommodate grades up to 18 percent at reduced speed could help mitigate this problem by going directly from aerial to subway. Switching and the structures needed to support switches result in a significant cost increase.

Rubber Tired Monorail

Monorail has a large following of devotees and has several systems successfully operating. With a wide body vehicle, such a system is a viable urban transportation option. Monorail is also capable of grades steeper than 6 percent, but in this case, the cost of increased maintenance should be considered. The “I” beam, due to its reduced torsional resistance, requires shorter spans on curved sections. Switching and the structures needed to support switches result in a significant cost increase.

Except for switching along guideways and in yards, all three of the above solutions are assumed to require aerial guideway structures of similar cost. It might be said that a monorail is a simpler guideway, but monorail requires a continuous walkway for maintenance and emergency exiting, and some structure is advisable to support the collection of wheel and brake dust. For this report, the guideway configurations and costs needed to support light rail transit are assumed applicable for all three modes discussed above.

Aerial Guideway

The following are considered during for investigation:

- Design standard curvature, span configurations, single vs. double girders, pier and foundation types, and concrete strength.
- Pre-cast and cast-in-place forms and false work
- Delivery length and weight of girder elements
- Erection schedules

For the purpose of this review, design-build project delivery is to be assumed. Various configurations and construction solutions using precast and cast-in-place concrete girders, cast-in-place concrete and structural steel piers, and single and multiple drilled shaft foundations are discussed. In addition, issues perceived as potential concerns, and that might arise regardless of the alternative being investigated as a standard guideway girder, are also addressed.

The design-build contracting method for project delivery is central to the question of establishing “standard” construction structural details and aesthetic principles. This review lists and evaluates the major factors a standard guideway construction solution will have on design-build delivery in the field for constructability, cost, schedule, and interference with traffic for most conditions encountered in the field.

Construction Options Considered

The specific construction elements and solutions considered are post-tensioned segmental girders, precast-prestressed box girders, and cast-in-place post-tensioned girders: See Figure 1.4 for the common span capabilities for these various types of construction.

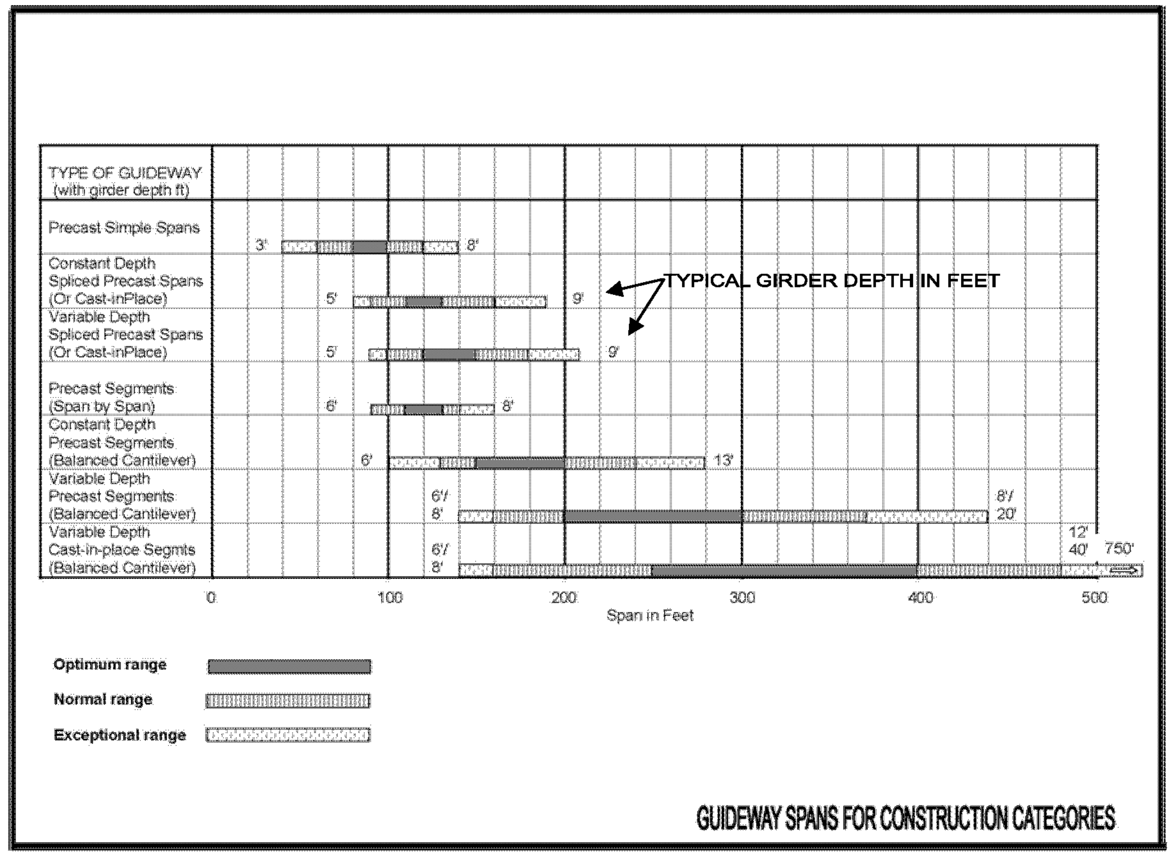

Figure 1-4. Guideway Spans for Construction Categories

Post-tensioned segmental girders

The following are considerations to be taken into account when selecting segmental girder construction:

- Precast with epoxied joints or cast-in-place;
- Span by span or balanced cantilever;
- Cross-sections supporting either single or double trackways;
- Roadway lanes, and the double trackways supporting special trackwork such as crossovers. Individual girders weigh less during construction but require shorter spans on curves.

Managed Roadway Lanes

The common solution is to consider a single girder as wide as possible, and to use two girders when the width exceeds the practicality of one girder. For managed roadways in this corridor, the following configurations are applicable:

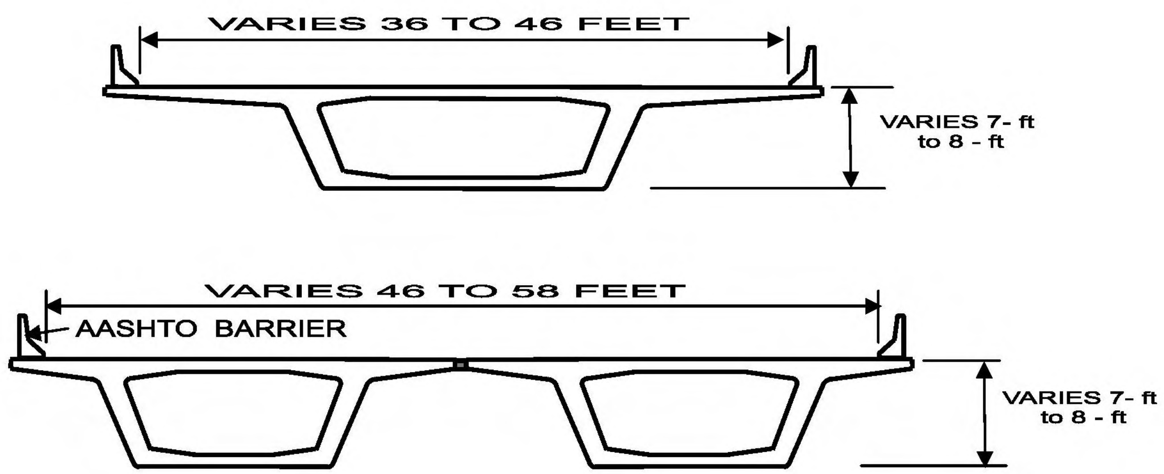

Figure 1-5. Managed Lanes Single-Girder (top) and Two-Girder Configuration

Rail Transit Girders

For double track rail transit, two configurations are considered:

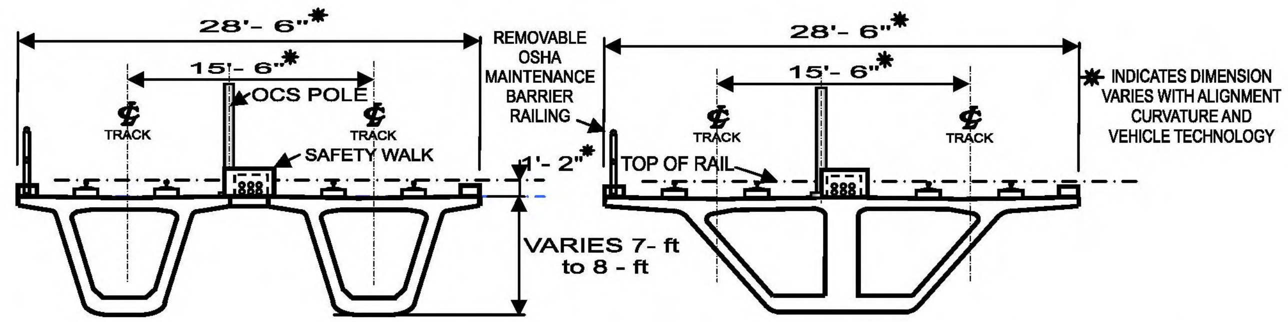

Figure 1-6. Rail Transit Single Track Girders (left) and Dual Track Girders

Continuous Precast Post-tensioned or Simple Span Prestressed Box Girders

Long span precast box girders are feasible if their width is sufficiently narrow to minimize the construction handling length and weight. Wide structurally integral decks can be achieved by connecting adjacent units or using a cast-in-place deck course. Cast-in-place decks composite with precast "U" cross-sections are not possible using long narrow precast structural elements due to the stability problems associated with transporting them or placing them on curved sections prior to casting the deck. Precast box solutions can also be made capable of supporting special trackwork by providing a third precast element for the case of a center platform station.

Managed Roadway Lanes
Multiple precast girders, either as boxes, "T" sections, or "I" sections are the most common solutions for long precast girders due to the weight of trying to lift both long and wide girder sections:

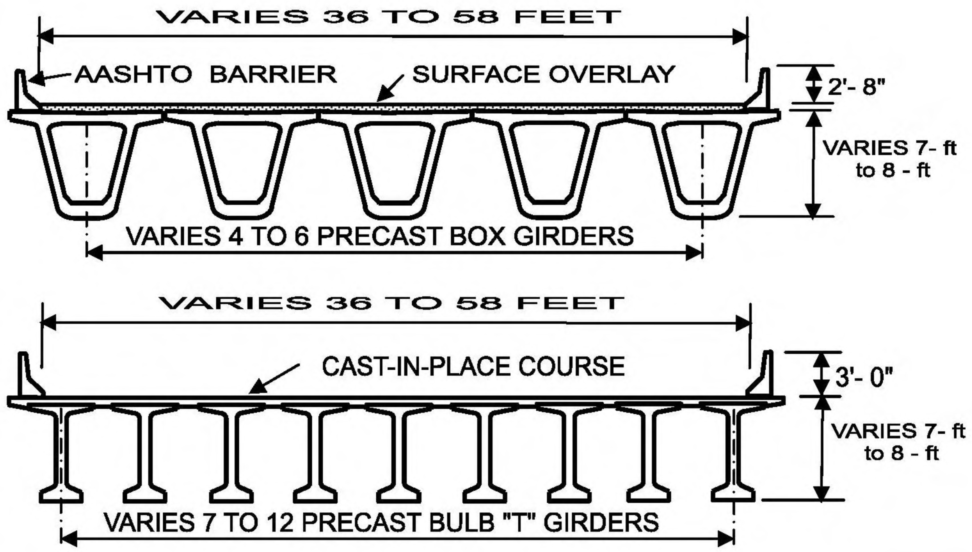

Figure 1-7. Multiple Precast Box (top) and "T" Girders

Rail Transit Girders
For double track rail transit, only two single-track box girders are considered due to the heavy weight associated with lifting one double-track girder:

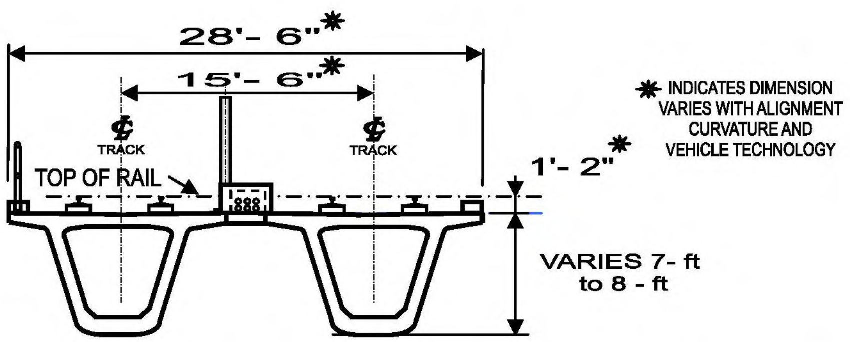

Figure 1-8. Rail Transit Single-Track Box Girders

Cast-in-Place Post-Tensioned Girders

Managed Roadway Lanes
For cast-in-place roadway lanes, the number of box cells varies from 3 to 5 for the widths presently assumed, and as small as one or two for the on and off ramps:

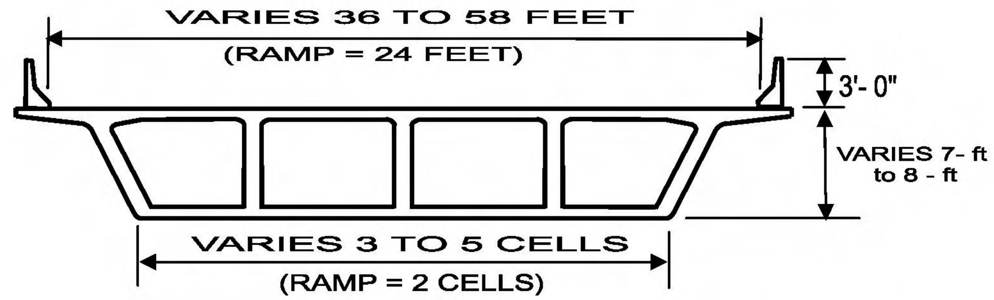

Figure 1-9. Managed Lanes Cast-in-Place Girders

Rail Transit Girders
For double track rail transit, only one double-track girder is considered economic for cast-in-place guideway due to the increase in formwork and reinforcing placement if two single tracks are used. Where center platform stations are used, the tracks split for a short distance as two single-track girders:

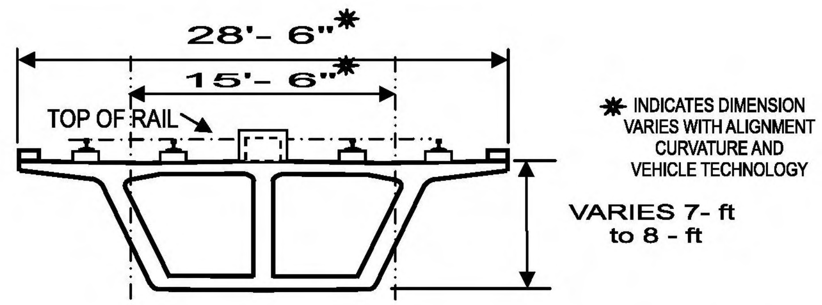

Figure 1-10. Rail Transit Cast-in-Place Girders

Pier Columns, Pier Caps, and Pier Tables

Pier columns, pier caps, and pier tables can be either cast-in-place or structural steel. These are shown in this section only in concrete, but structural steel will reduce the column size substantially, especially for multiple columns and "C" bents shown in Figure 1-11.

The cost for structural steel is greater, but may reduce right-of-way takes, or even avoid a space restriction that would otherwise make construction unfeasible. Structural steel sections can be encased in concrete, giving it the same service life in a corrosive environment as reinforced concrete, and yet have a smaller space requirement. Steel pipe columns may be purchased with a concrete corrosion resistant coating already affixed to its external surface.

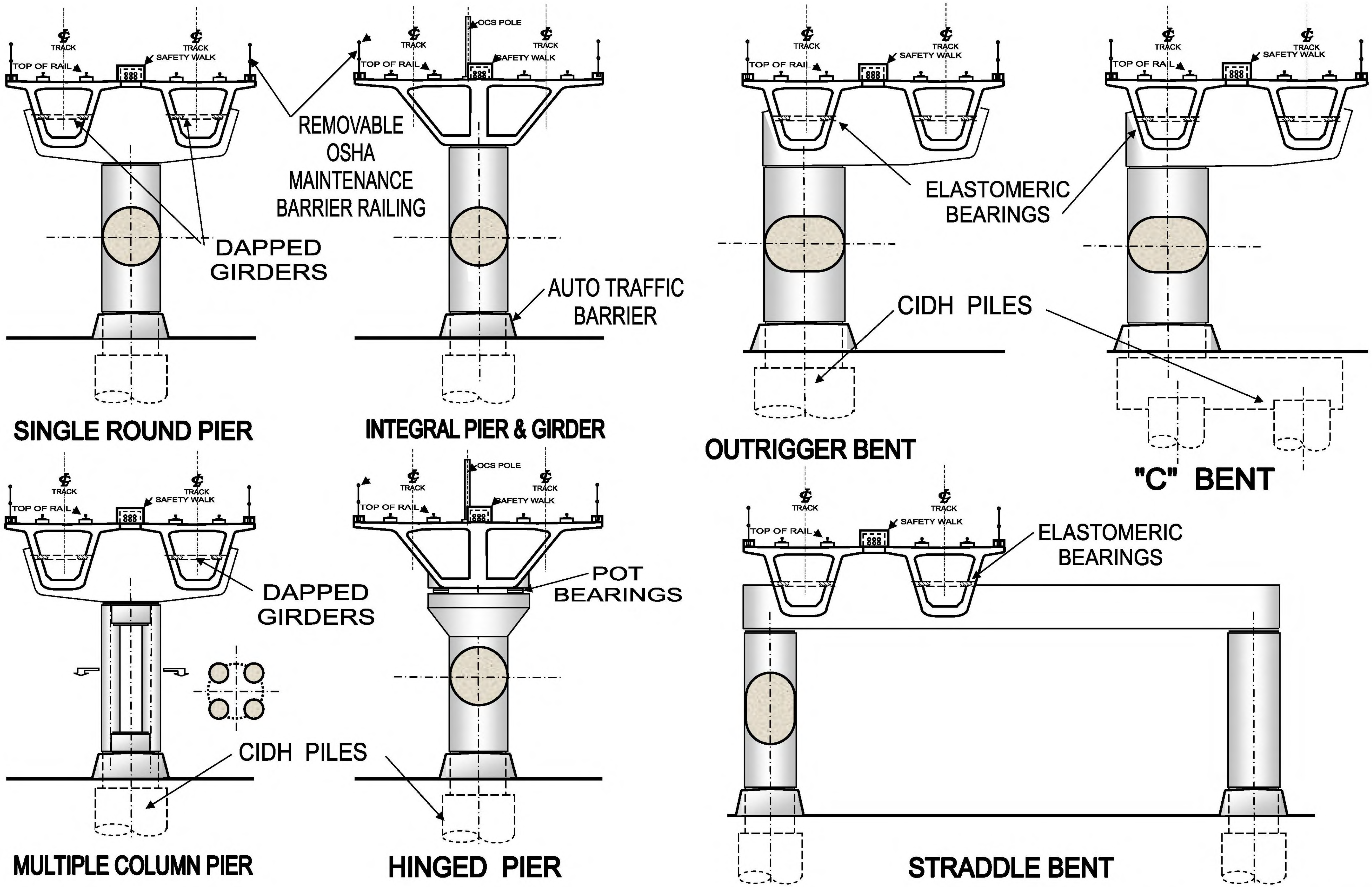

Figure 1-11. Guideway Spans for Construction Categories

The following examples have been shown in Figure 1-11:

- Single Round Pier and Multiple Column Piers;
- Integral Pier & Girder and Hinged Piers;
- Outrigger, "C", and Straddle Bents.

Pier Foundation Support

Pier foundation support is either by multiple drilled shafts with cast-in-place caps, or a single drilled shaft with or without cast-in-place caps.

Single drilled shafts (cast in drilled hole [CIDH] piles) for circular pier sections are preferred to multiple pile foundations requiring a pile cap. Drilled shafts take the least street or right-of-way area, conflict with the least utilities, and require no footing excavation dewatering or flood control protection. Two drilled shafts are nevertheless expedient for pier columns made elliptical in shape due to a narrow median, and also for "C" bent construction. Multiple CIDH piles will likely be used for abutments.

Span Configurations

Nearly unlimited simple versus continuous span configurations and bearing arrangements are possible for either precast or cast-in-place box girder solutions. Structural stability on curves and maximum span length is promoted by girder continuity. The controlling factor for span length is the depth of standard cross-section selected for either solution. The span economic length is the economic girder depth that is most advantageous for the construction of the standard span solution.

Because of temperature change and transit vehicle forces acting on the continuous running rail, the maximum continuous span between expansion joints should be limited to about 500 feet for rail transit. Managed lanes might accommodate longer spans, but will be assumed the same for this comparative study. Some possible configurations leading up to this limiting distance are:

Precast Segmental and Precast Spliced Girder Spans

For girders depths from 7 to 8 feet, the following span configurations are appropriate:

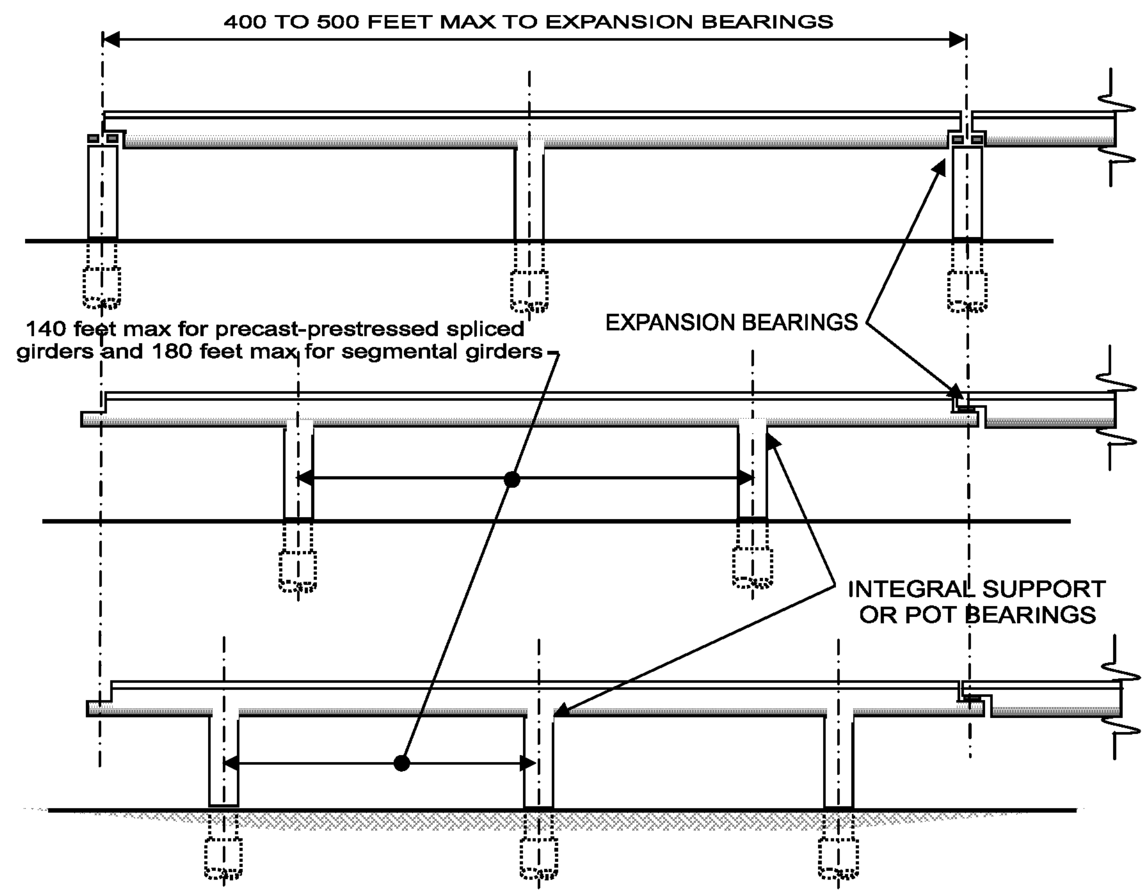

Figure 1-12. Precast Segmental and Precast Spliced Girder Plans

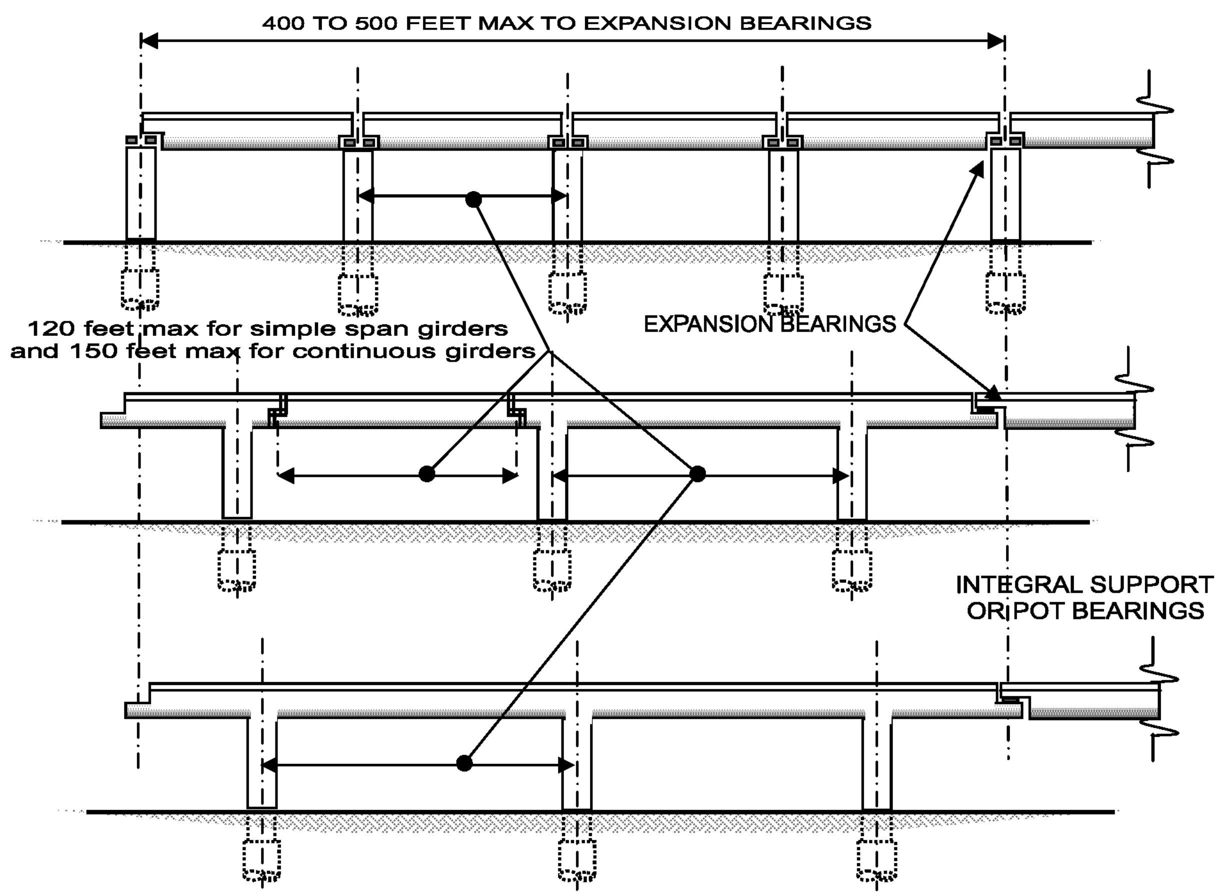

Figure 1-13. Precast Simple, and Cast-in-Place Simple and Continuous Spans

Managed Lane Alternatives

For managed lane alternatives, there are several changes in roadway widths and super elevation due to curves, on-off ramps, and merging lanes. These variations, as shown in Figure 1-5, require a variety of precast segments, and therefore, flexibility of precast forms. Cantilever construction will sometimes be required causing more disruption to the roadways below than the typical span by span erection.

For the purpose of this study, forms for 3 different precast, match-cast segments are anticipated to accommodate the 4 different deck widths and the roadway super-elevation required. Unlike rail transit employing adjustable rail plinths or ballast to accommodate super-elevation, a roadway running surface must accomplish this in the formwork. These assumptions are recommended for schedule and cost estimating. The following are the main characteristics of the structure to be detailed:

- Single cell, precast segmental, post-tensioned trapezoidal box girders for all roadways;
- Box girder sections to be 7-foot deep, and from 28 to 62 feet wide;
- Spans vary from 90 to 150 feet with 17-foot 6-inch clearance below soffit. An average span of 120 feet is therefore assumed for quantities;
- Piers circular or oval depending on available space in median or other right of way;
- Special precast column segment to be cast integral with piers with elastomeric bearings at expansion, and at suspended and abutment bearings.

Roadway Structural Details

Attached Figures 2-1 through 2-4 indicate the precast segmental girder details anticipated for the roadway construction. Three different segments are assumed required to accommodate the 4 roadway widths. That is, Figures 2-1 and 2-3 are assumed to use the same segment with minor modification of the forms.

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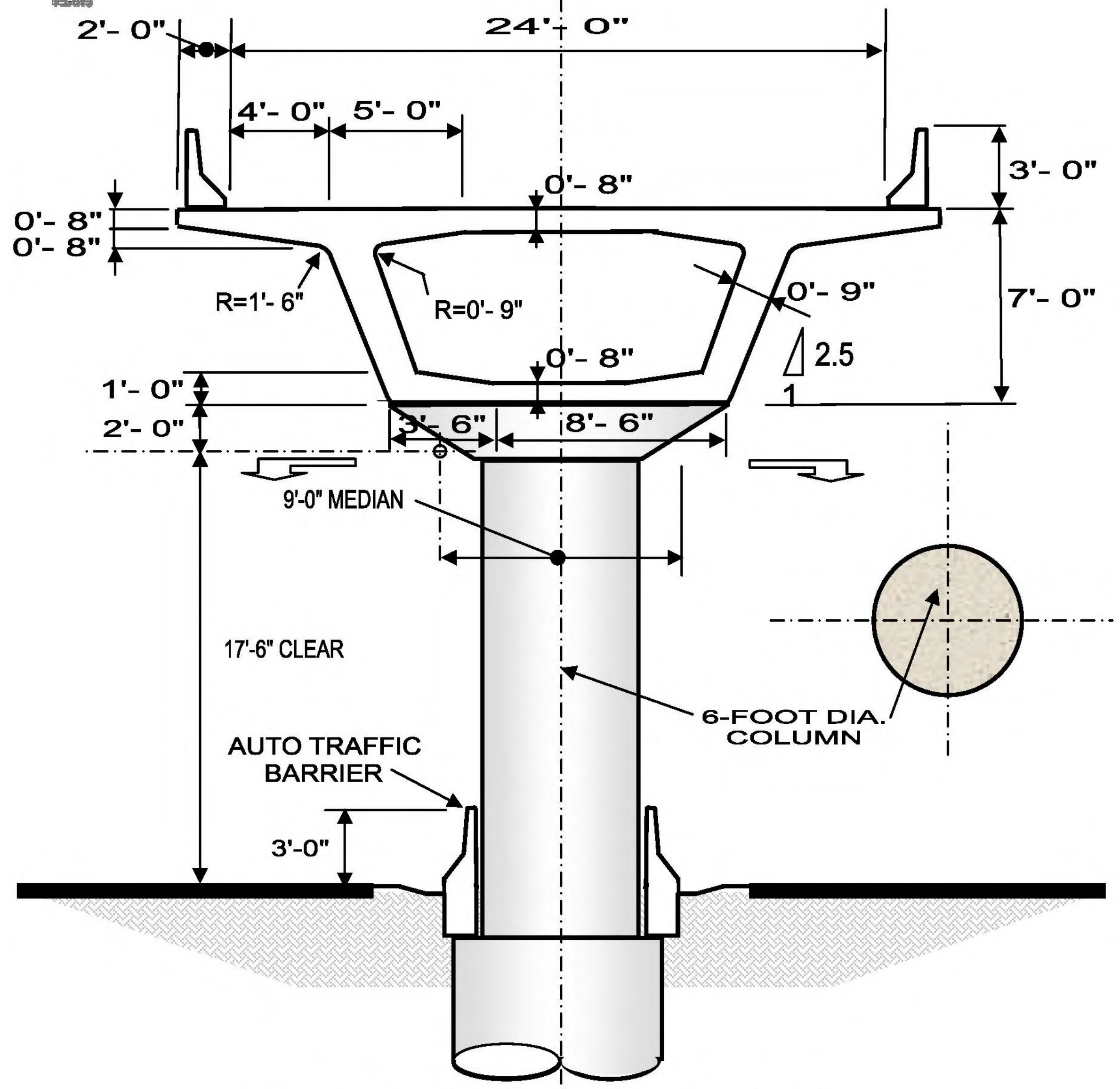


PRECAST SEGMENTAL ROADWAY SECTION

PER FOOT QUANTITIES FOR 120-FOOT AVERAGE SPAN					
ROADWAY WIDTH	GIRDER CONCRETE 5000 PSI	COLUMN CONCRETE 5000 PSI	DRILLED SHAFT CONCRETE 4500 PSI	MILD STEEL REINFORCING Fy = 60 KSI	PRESTRESS STEEL Fpu = 270 KSI
24-FOOT	2.08 C.Y.	0.17 C.Y.	0.35 C.Y.	275 LBS/FT	52 LBS/FT

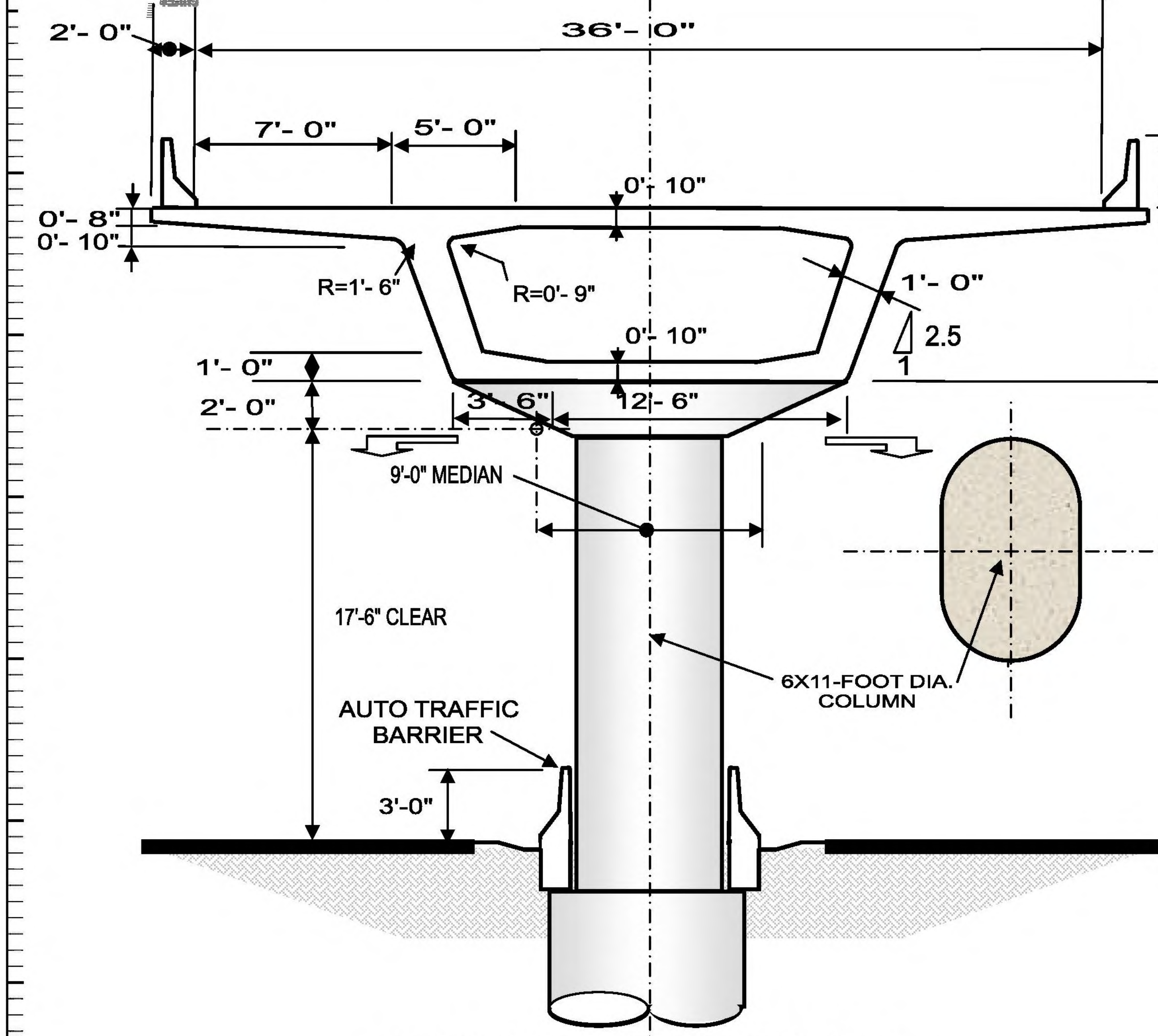
COLUMN AND DRILLED SHAFT FOR 120-FOOT AVERAGE SPAN		
ROADWAY WIDTH	COLUMN SIZE	DRILLED SHAFT NUMBER & SIZE
24-FOOT	6 FT DIA	6 FT DIA X 40 FT LONG

FIGURE 2-1

PRECAST SEGMENTAL GIRDER DETAILS FOR AERIAL ROADWAY CONSTRUCTION TABLE OF STRUCTURAL DETAILS FOR AVERAGE SPAN OF 120 FEET

24-FOOT ROADWAY

PARSONS BRINCKERHOFF



PRECAST SEGMENTAL ROADWAY SECTION

PER FOOT QUANTITIES FOR 120-FOOT AVERAGE SPAN					
ROADWAY WIDTH	GIRDER CONCRETE 5000 PSI	COLUMN CONCRETE 5000 PSI	DRILLED SHAFT CONCRETE 4500 PSI	MILD STEEL REINFORCING Fy = 60 KSI	PRESTRESS STEEL Fpu = 270 KSI
36-FOOT	3.04 C.Y.	0.25 C.Y.	1.30 C.Y.	485 LBS/FT	76 LBS/FT

COLUMN AND DRILLED SHAFT FOR 120-FOOT AVERAGE SPAN		
ROADWAY WIDTH	COLUMN SIZE	DRILLED SHAFT NUMBER & SIZE
36-FOOT	6 X 11 FT	2-8 FT DIA X 45 FT LNG

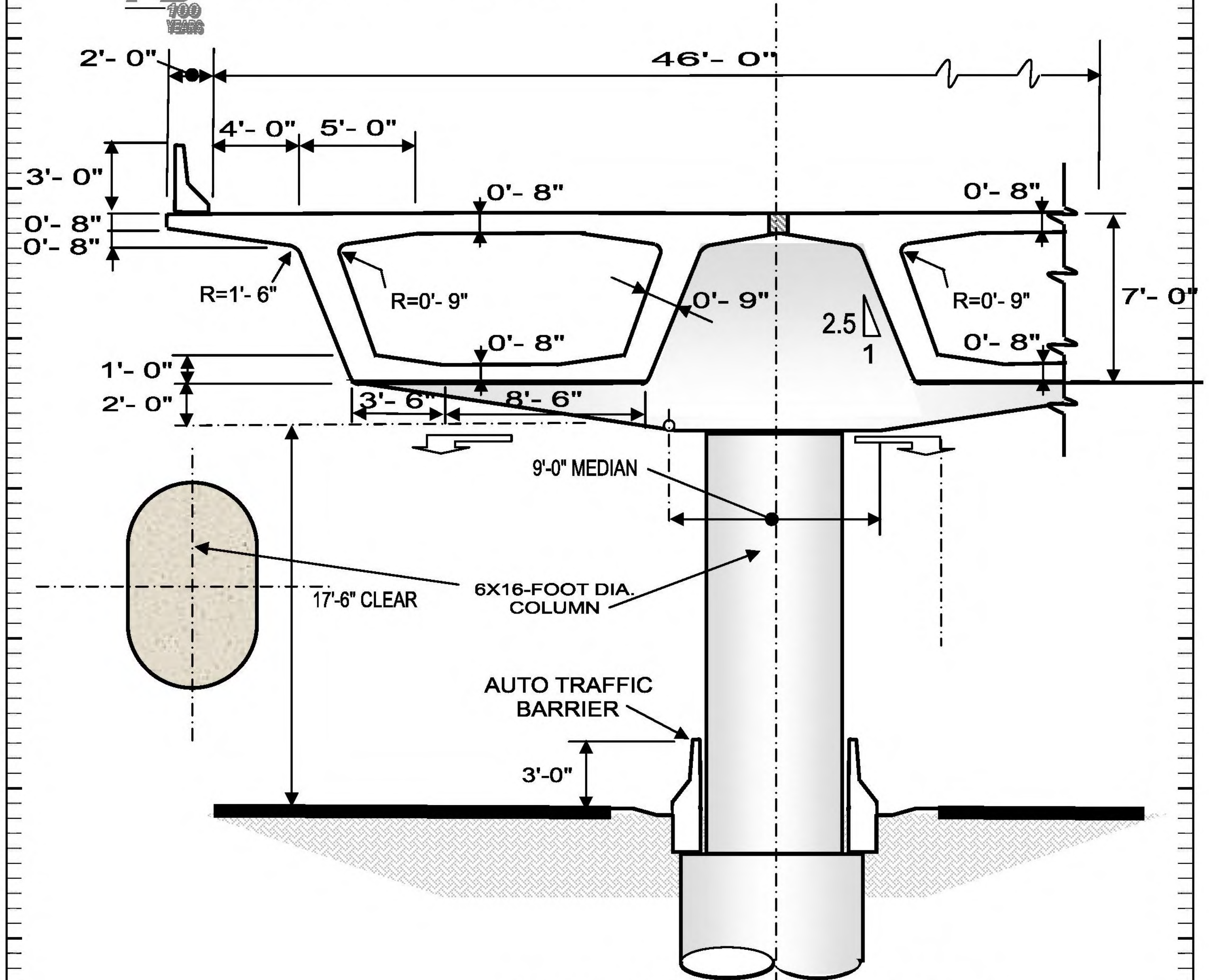
FIGURE 2-2

PRECAST SEGMENTAL GIRDER DETAILS FOR AERIAL ROADWAY CONSTRUCTION TABLE OF STRUCTURAL DETAILS FOR AVERAGE SPAN OF 120 FEET

36-FOOT ROADWAY

calculation

PARSONS BRINCKERHOFF



PRECAST SEGMENTAL ROADWAY SECTION

PER FOOT QUANTITIES FOR 120-FOOT AVERAGE SPAN					
ROADWAY WIDTH	GIRDER CONCRETE 5000 PSI	COLUMN CONCRETE 5000 PSI	DRILLED SHAFT CONCRETE 4500 PSI	MILD STEEL REINFORCING Fy = 60 KSI	PRESTRESS STEEL Fpu = 270 KSI
46-FOOT	3.89 C.Y.	0.53 C.Y.	1.50 C.Y.	640 LBS/FT	97 LBS/FT

COLUMN AND DRILLED SHAFT FOR 120-FOOT AVERAGE SPAN		
ROADWAY WIDTH	COLUMN SIZE	DRILLED SHAFT NUMBER & SIZE
46-FOOT	6 X 16 FT	2-8 FT DIA X 60 FT LNG

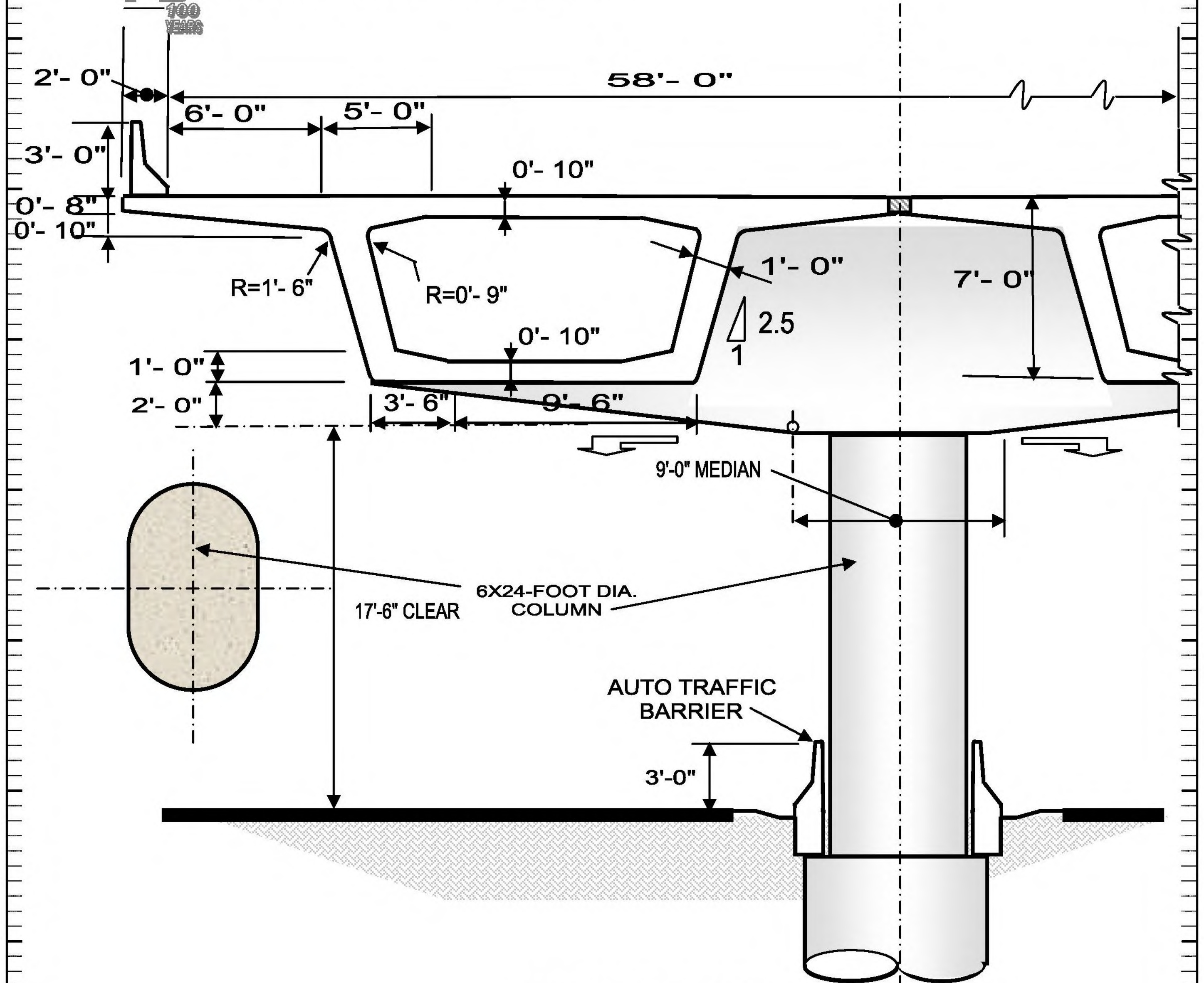
FIGURE 2-3

PRECAST SEGMENTAL GIRDER DETAILS FOR AERIAL ROADWAY CONSTRUCTION TABLE OF STRUCTURAL DETAILS FOR AVERAGE SPAN OF 120 FEET

46-FOOT ROADWAY

calculation

PARSONS BRINCKERHOFF



PRECAST SEGMENTAL ROADWAY SECTION

PER FOOT QUANTITIES FOR 120-FOOT AVERAGE SPAN					
ROADWAY WIDTH	GIRDER CONCRETE 5000 PSI	COLUMN CONCRETE 5000 PSI	DRILLED SHAFT CONCRETE 4500 PSI	MILD STEEL REINFORCING Fy = 60 KSI	PRESTRESS STEEL Fpu = 270 KSI
58-FOOT	5.37 C.Y.	0.82 C.Y.	1.60 C.Y.	845 LBS/FT	134 LBS/FT

COLUMN AND DRILLED SHAFT FOR 120-FOOT AVERAGE SPAN		
ROADWAY WIDTH	COLUMN SIZE	DRILLED SHAFT NUMBER & SIZE
58-FOOT	6 X 24 FT	2-8 FT DIA X 70 FT LNG

FIGURE 2-4

PRECAST SEGMENTAL GIRDER DETAILS FOR AERIAL ROADWAY CONSTRUCTION TABLE OF STRUCTURAL DETAILS FOR AVERAGE SPAN OF 120 FEET

58-FOOT ROADWAY

Fixed Guideways

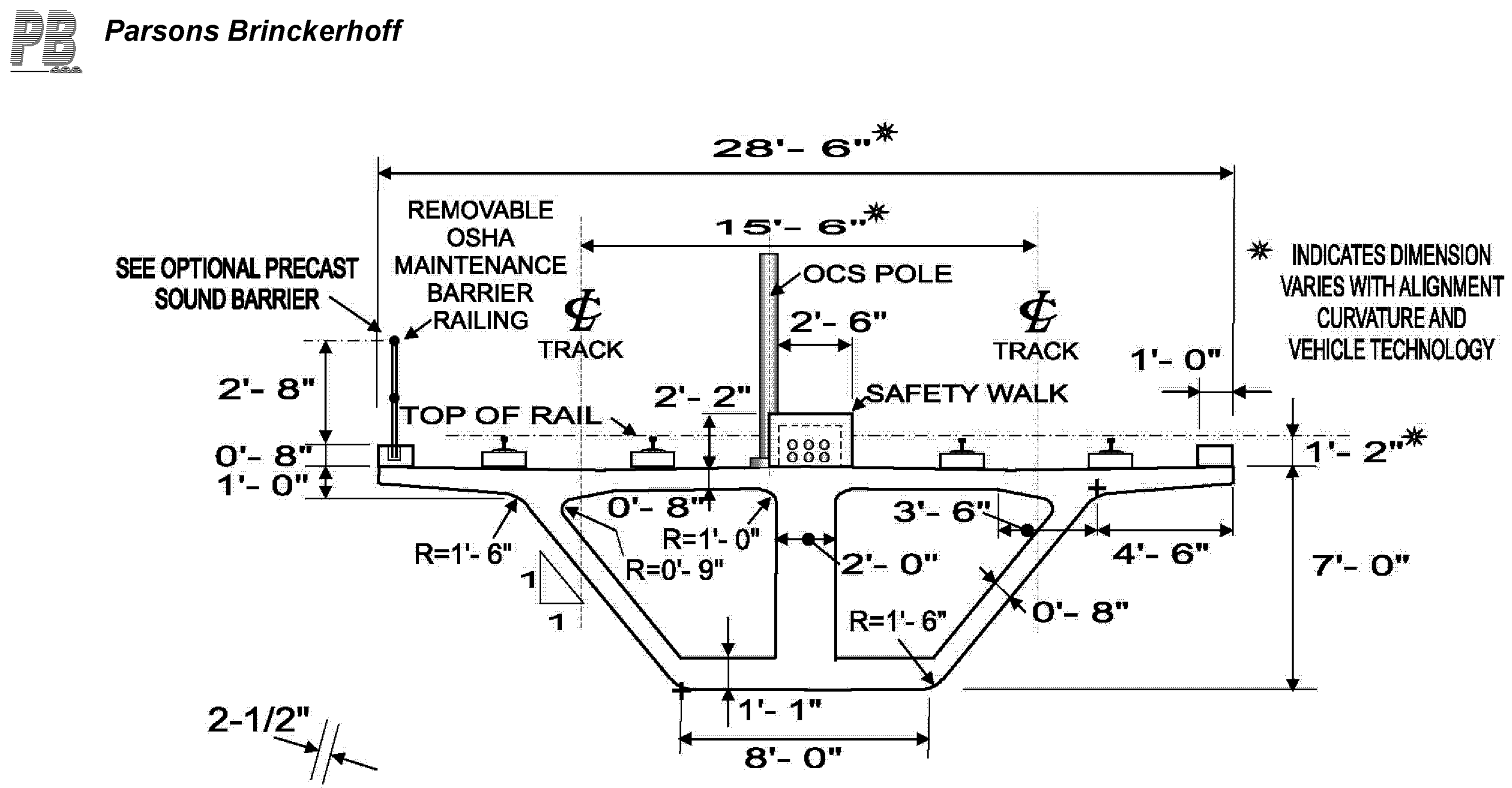
For light rail, maglev, and monorail, experience has shown for corridors similar to that planned, precast segmental girders are particularly cost and schedule effective. They are also publicly beneficial aesthetically while minimizing the construction disruptions. The main characteristics of the planned system are its two closely spaced vehicle guideways and its mostly side platform stations, making the casting of a single guideway girder element to support dual tracks possible through station areas.

Span by span segmental is the assumed method of guideway erection for beneficial schedule and precast unit transport reasons. It is not possible to predict exactly what solution a design-build contractor will find most acceptable for the equipment and experience he has with the various forms of construction. Therefore a middle of the road solution is chosen for the purpose of recommending structural details. All the vehicle technologies of equal service life will result in similar structural costs. The following are the main characteristics of the structure to be detailed:

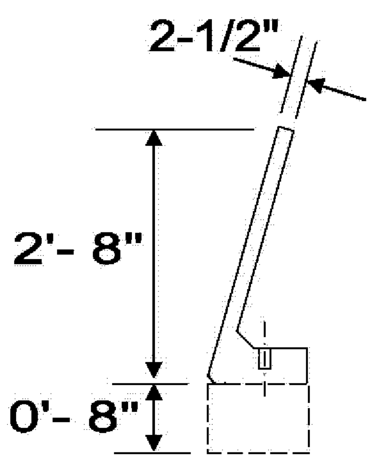
- Single precast segmental trapezoidal box for dual trackways;
- Precast segmental unit 7-foot deep, 9-foot long, and 28.5 feet wide (See Figures 2-5, 2-6 and 2-10 for segments using overhead contact system (OCS). See Figures 2-8, 2-9, 2-7, and 2-11 for segments using either 3RD rail system or OCS that also allow longer spans due to its integrally cast safety walk;
- Spans vary from 90 to 180 feet with 17-foot, 6-inch clearance below soffit;
- Piers circular or oval depending on available space in median or other right-of-way;
- Pot bearings at piers and at expansion and suspended bearings. Elastomeric bearings at abutments.

Fixed Guideway Details

The following sketches show typical details and erection procedures commonly employed. The use of an overhead self-launching truss minimizes disrupting the streets below with false work and construction equipment. Cantilever construction using the same precast elements erected from the street using cranes will be required on sharp curves, and also for split-level single-track girders that approach center platform stations. See Figures 2-5 through 2-15.



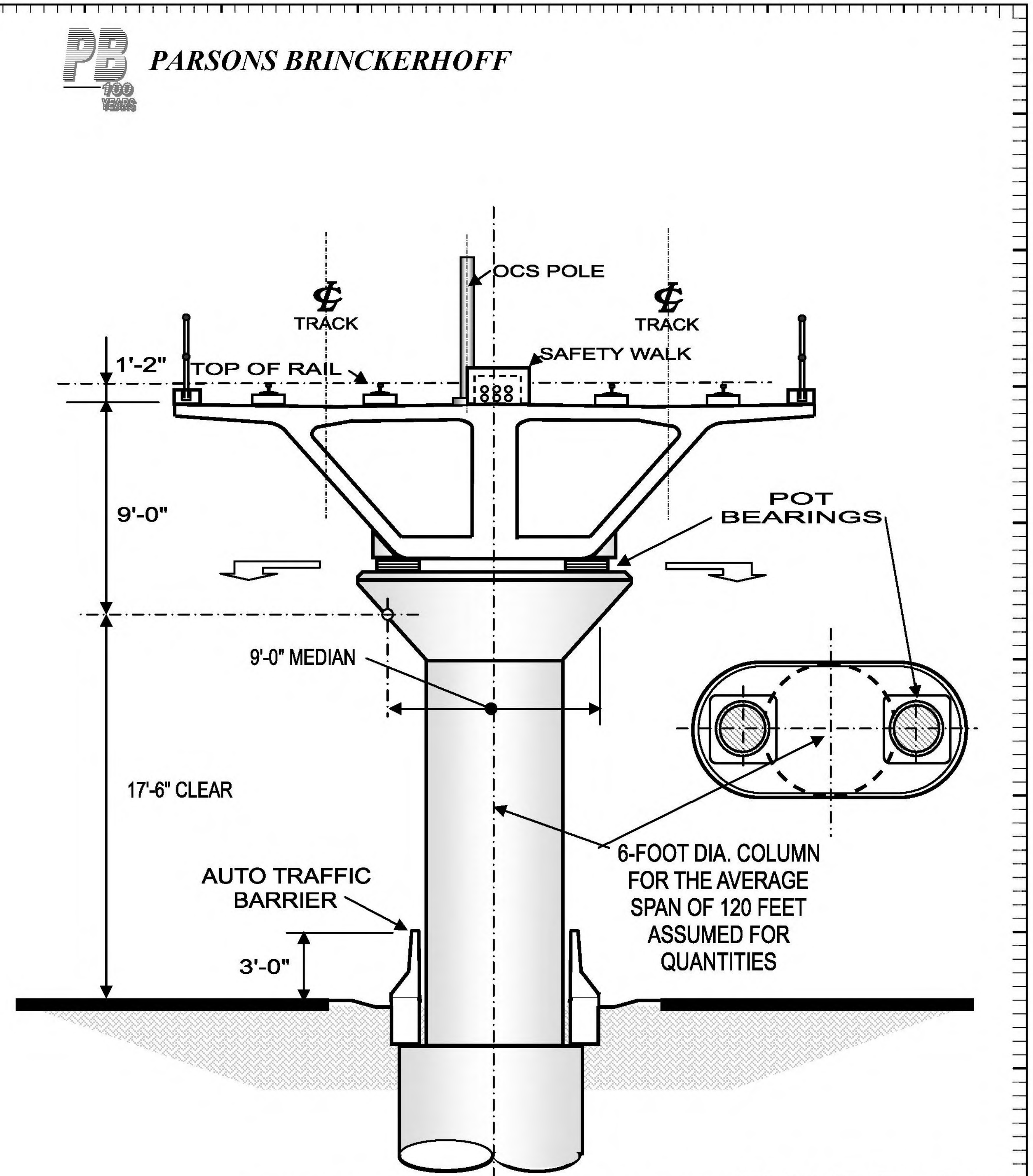
SEGMENTAL BOX GIRDER SECTION



OPTIONAL PRECAST SOUND BARRIER

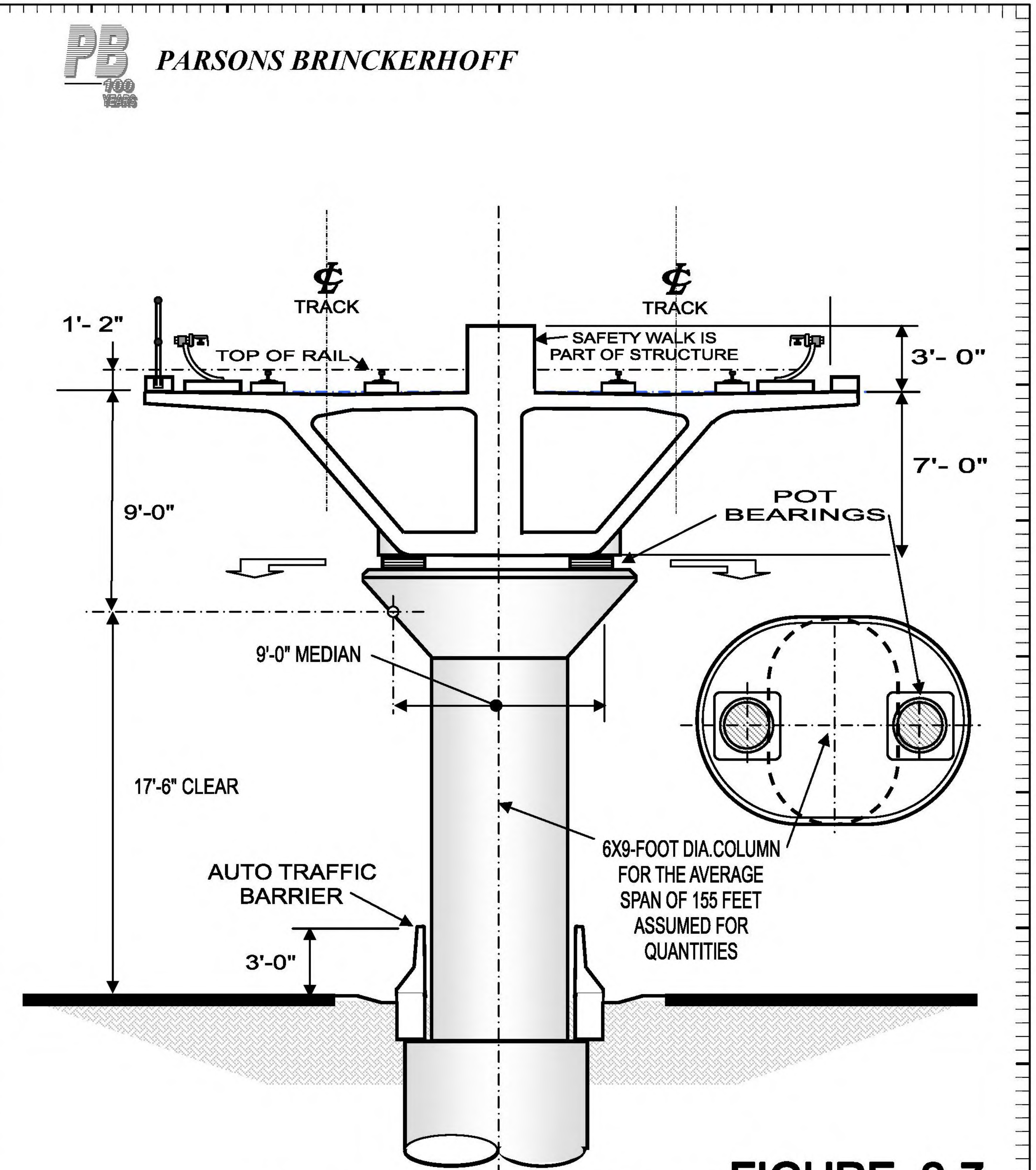
FIGURE 2-5

SEGMENTAL BOX GIRDER DETAILS FOR SPAN BY SPAN ERECTION OCS POLE CONFIGURATION 90-FOOT TO 130-FOOT SPANS



SEGMENTAL GUIDEWAY SECTION **FIGURE 2-6**

SEGMENTAL BOX GIRDER DETAILS
FOR SPAN BY SPAN ERECTION
OCS POLE CONFIGURATION
90-FOOT TO 130-FOOT SPANS



SEGMENTAL GUIDEWAY SECTION **FIGURE 2-7**

SEGMENTAL BOX GIRDER DETAILS
DOUBLE TRACK CANTILEVER ERECTION
3RD RAIL CONFIGURATION
130-FOOT TO 180-FOOT SPANS

calculation

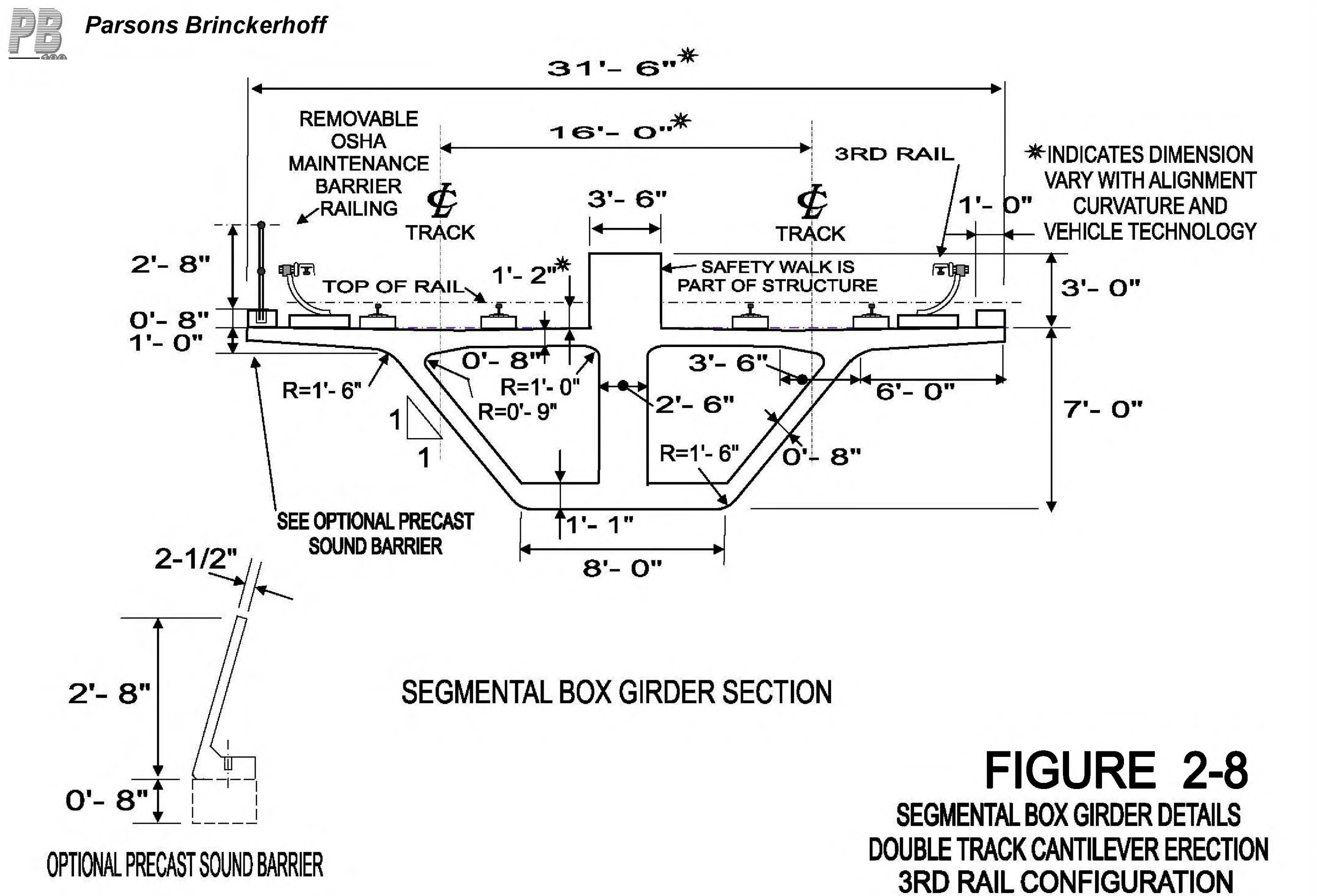


FIGURE 2-8

SEGMENTAL BOX GIRDER DETAILS
DOUBLE TRACK CANTILEVER ERECTION
3RD RAIL CONFIGURATION
130-FOOT TO 180-FOOT SPANS

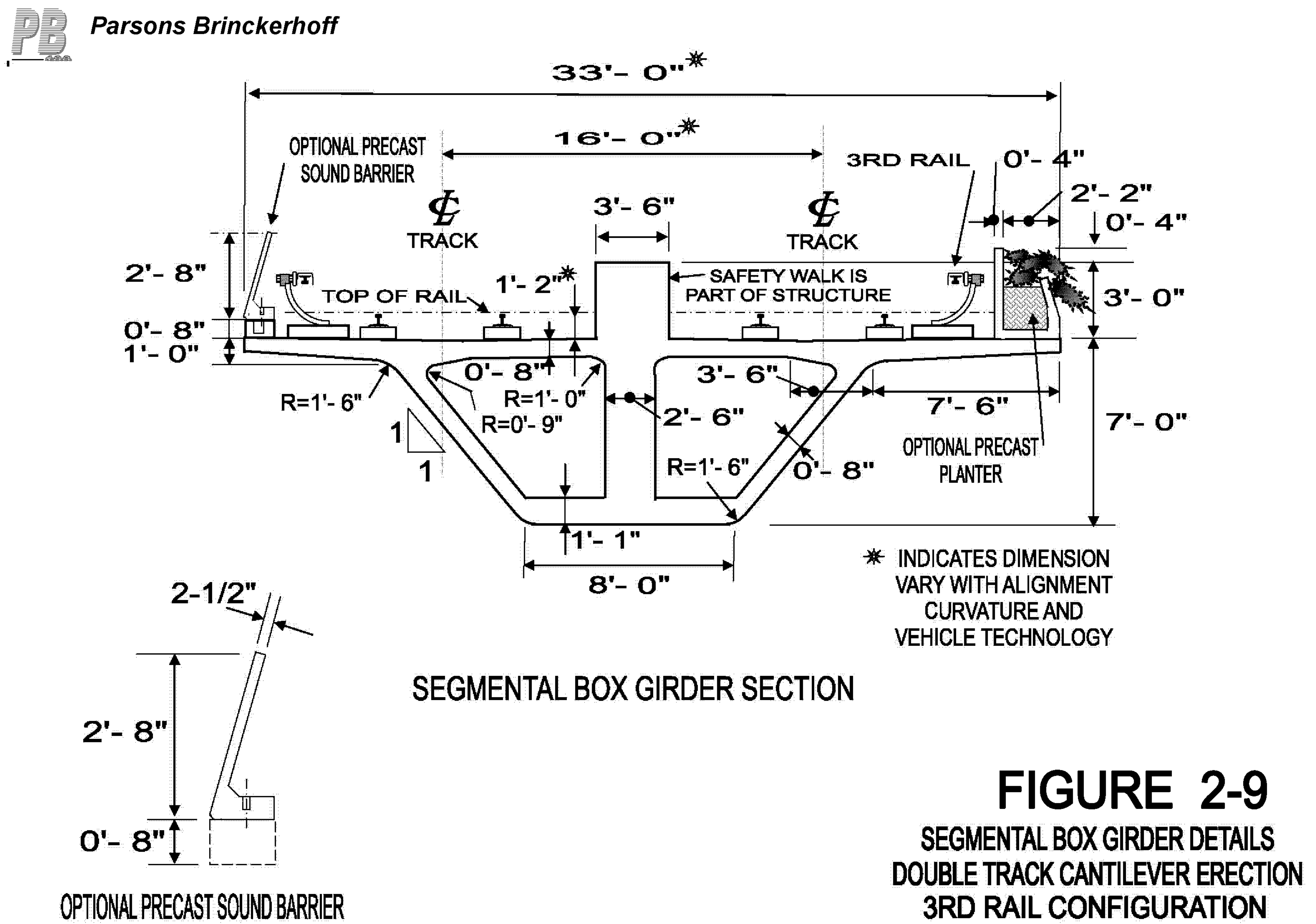
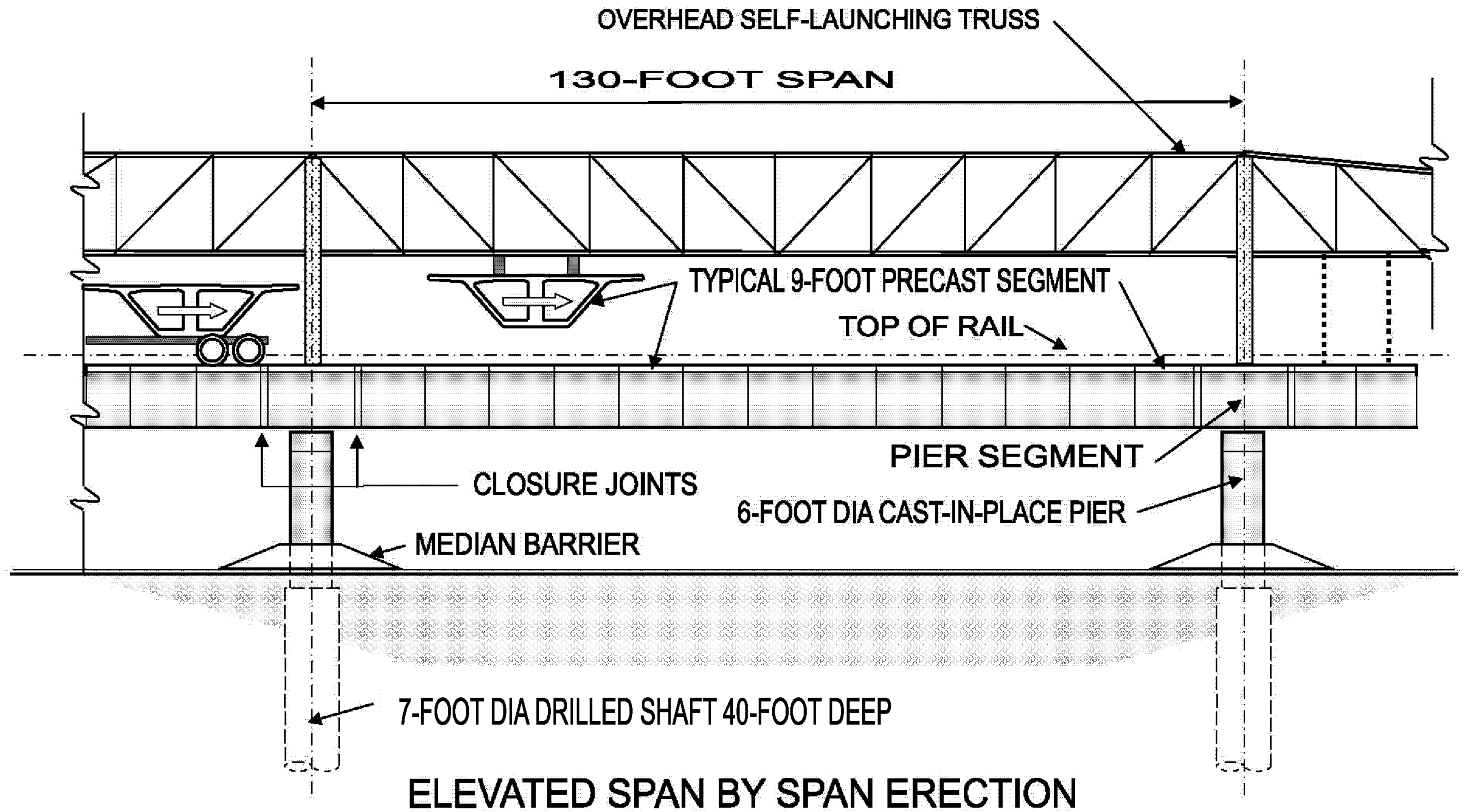


FIGURE 2-9

SEGMENTAL BOX GIRDER DETAILS
DOUBLE TRACK CANTILEVER ERECTION
3RD RAIL CONFIGURATION
130-FOOT TO 180-FOOT SPANS

Parsons Brinckerhoff

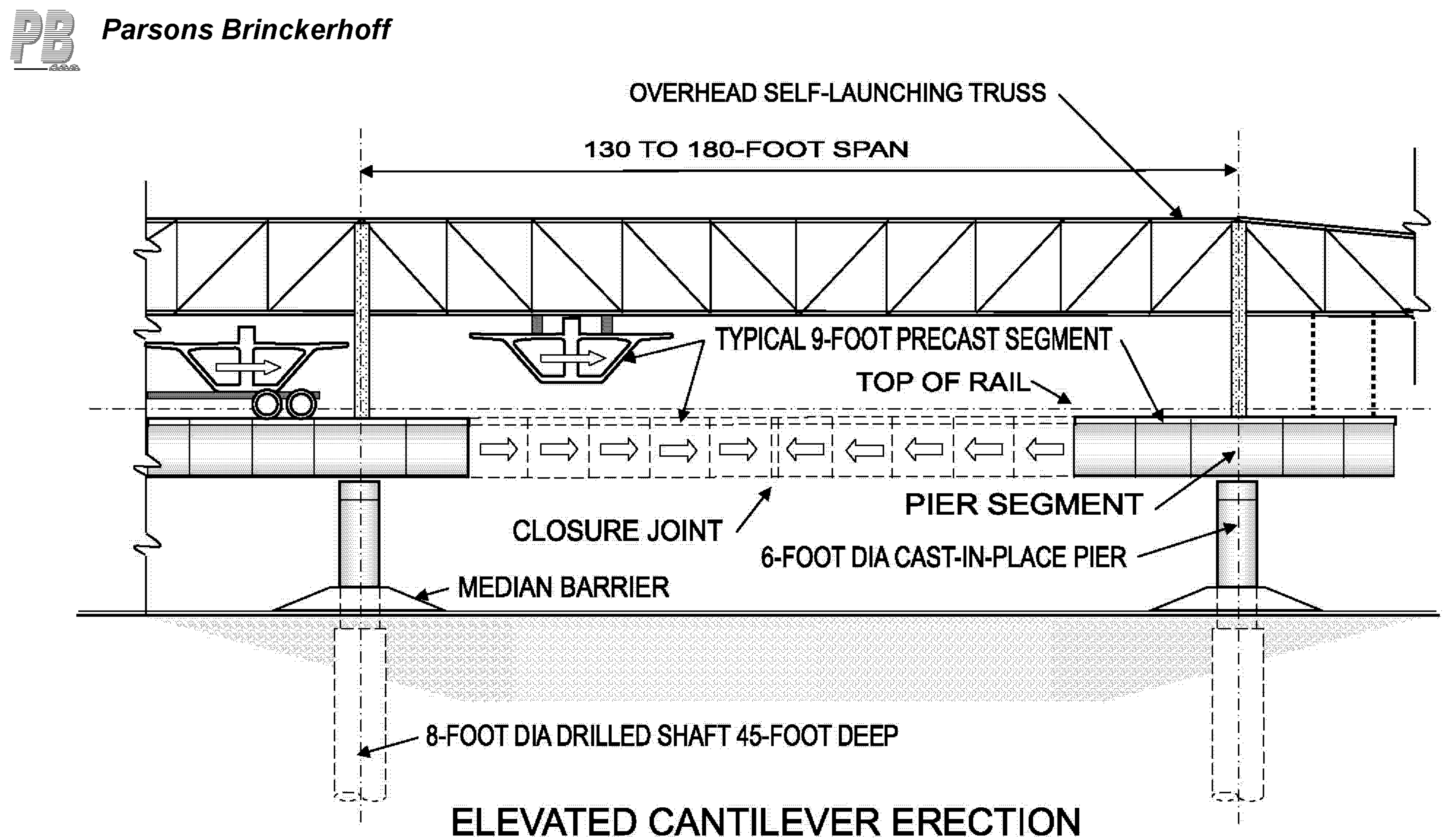


ELEVATED SPAN BY SPAN ERECTION

FIGURE 2-10

SEGMENTAL BOX GIRDER DETAILS FOR SPAN BY SPAN ERECTION

OCS POLE CONFIGURATION 90-FOOT TO 130-FOOT SPANS



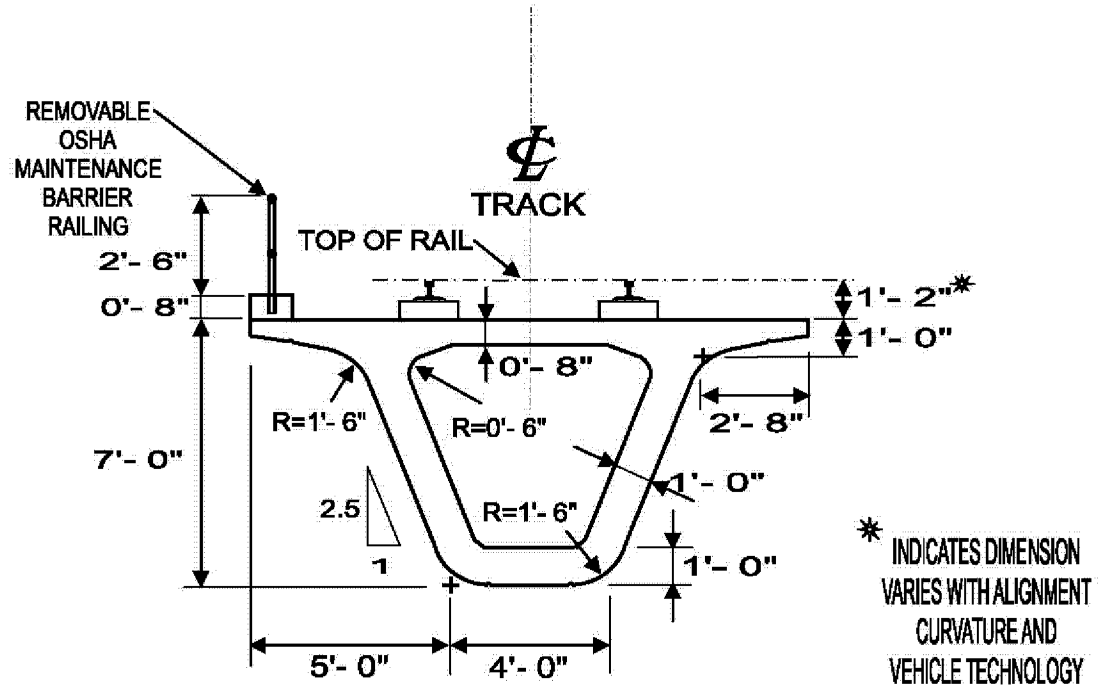
ELEVATED CANTILEVER ERECTION

FIGURE 2-11

SEGMENTAL BOX GIRDER DETAILS FOR CANTILEVER ERECTION

3RD RAIL CONFIGURATION
130-FOOT TO 180-FOOT SPANS

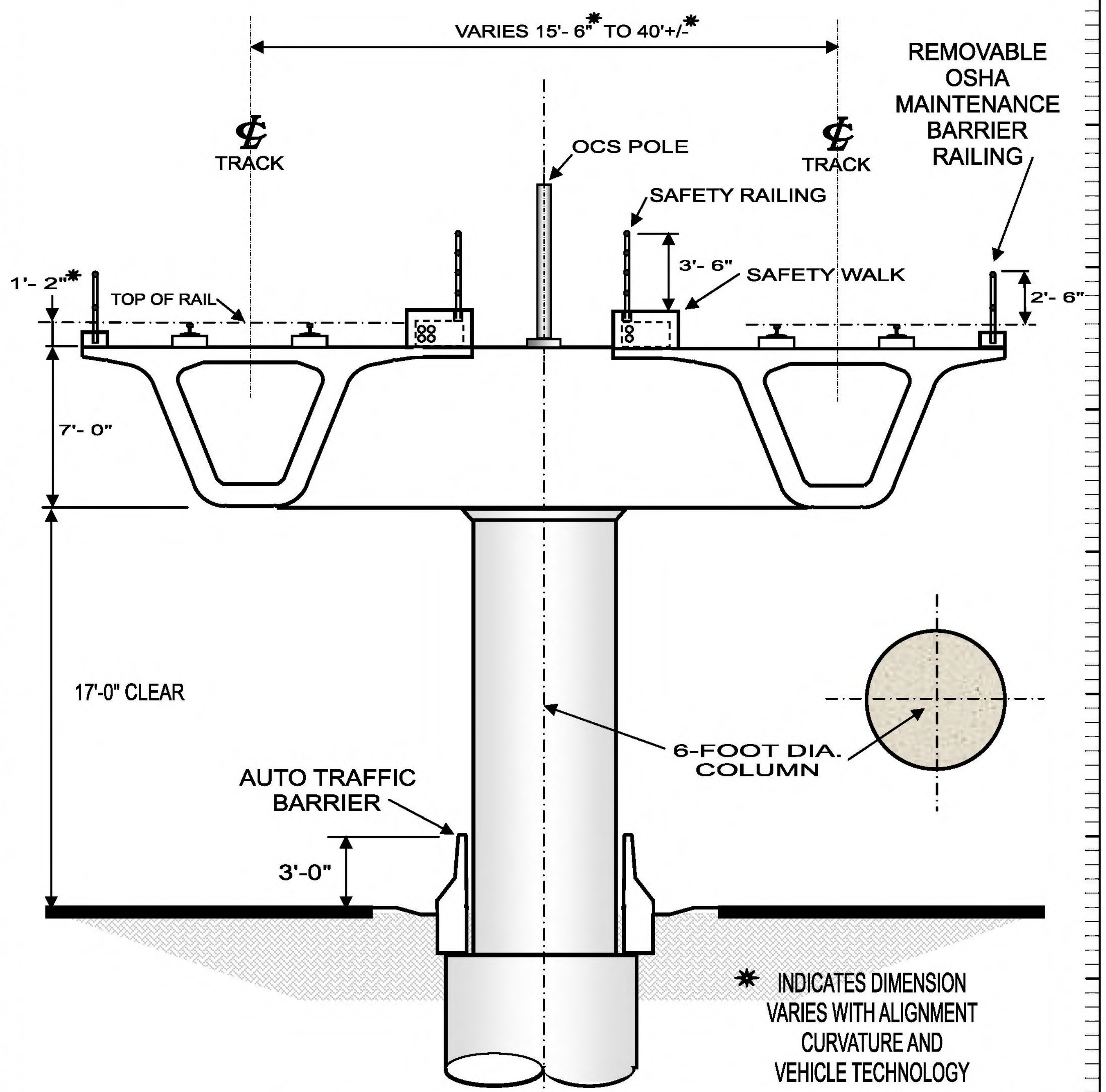
Parsons Brinckerhoff



SEGMENTAL BOX GIRDER SECTION

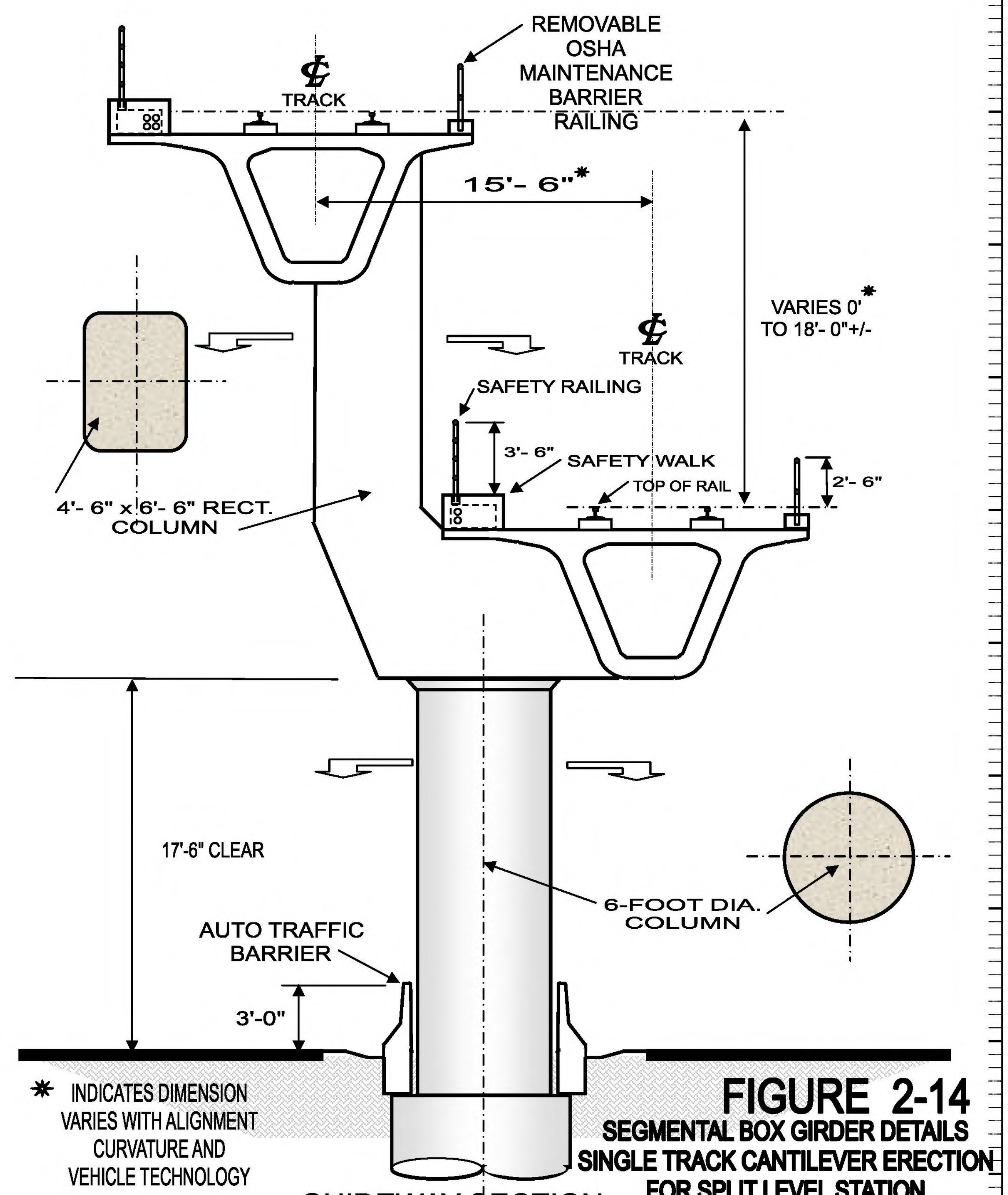
FIGURE 2-12

SEGMENTAL BOX GIRDER DETAILS SINGLE TRACK CANTILEVER ERECTION FOR APPROACH TO CENTER PLATFORM OF SPLIT LEVEL STATION PLATFORMS



SEGMENTAL GUIDEWAY SECTION **FIGURE 2-13**

SEGMENTAL BOX GIRDER DETAILS SINGLE TRACK CANTILEVER ERECTION FOR APPROACH TO CENTER PLATFORM STATION



GUIDEWAY SECTION

FIGURE 2-14

SEGMENTAL BOX GIRDER DETAILS SINGLE TRACK CANTILEVER ERECTION FOR SPLIT LEVEL STATION

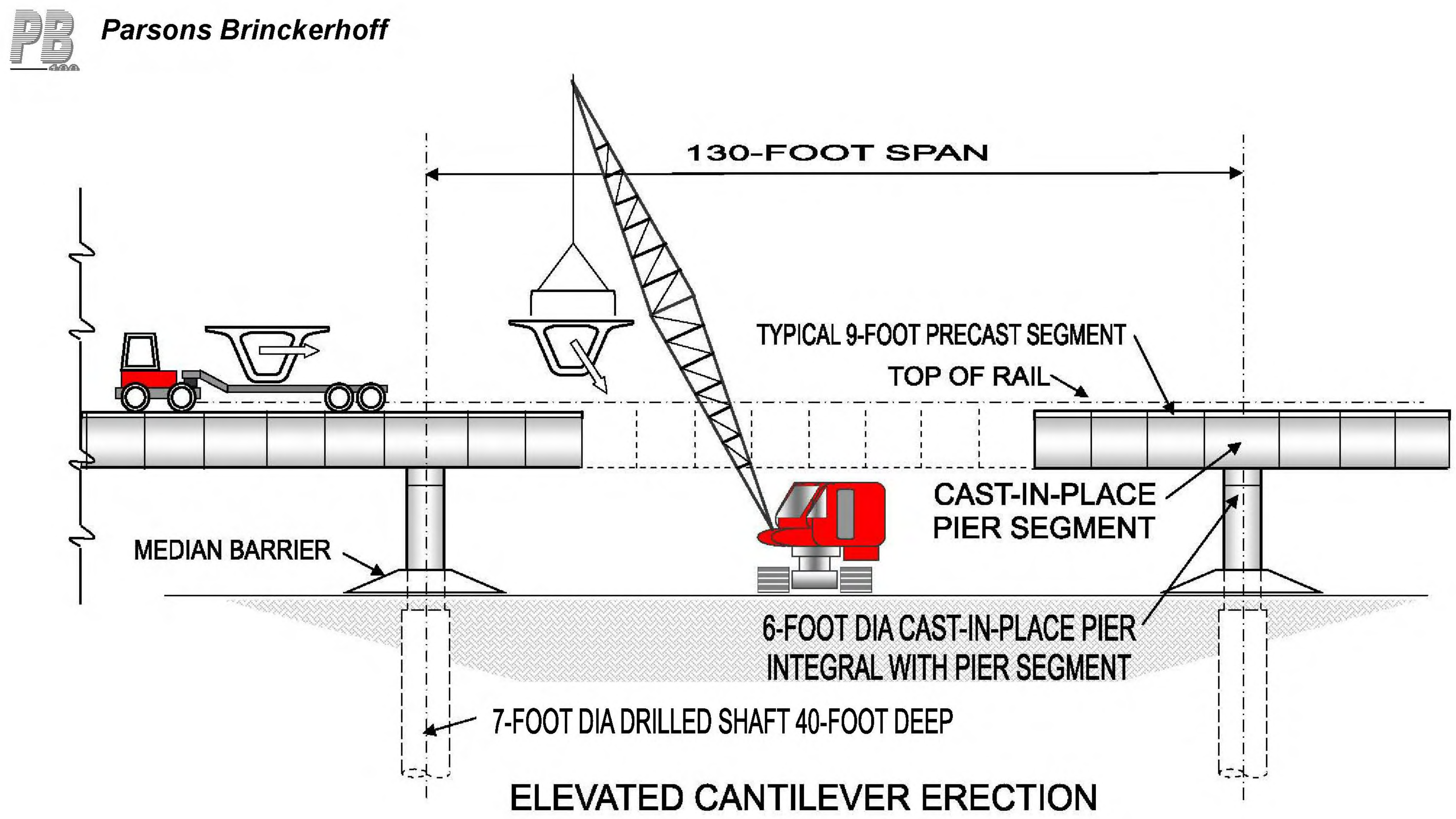


FIGURE 2-15
SEGMENTAL BOX GIRDER DETAILS
SINGLE TRACK CANTILEVER ERECTION
APPROACH TO CENTER PLATFORM
OF SPLIT LEVEL STATIONS